Can ultra-low-dose computed tomography reliably diagnose and classify maxillofacial fractures in the clinical routine?

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ABSTRACT

Purpose: Maxillofacial trauma predominantly affects young adults between 20 and 40 years of age. Although radioprotection is a legal requirement, the significant potential of dose reduction in computed tomography (CT) is still underused in the clinical routine. The objective of this study was to evaluate whether maxillofacial fractures can be reliably detected and classified using ultra-low-dose CT.

Materials and Methods: CT images of 123 clinical cases with maxillofacial fractures were classified by two readers using the AOCOIAC software and compared with the corresponding results from post-treatment images. In group 1, consisting of 97 patients with isolated facial trauma, pre-treatment CT images at different dose levels (volumetric computed tomography dose index: ultra-low dose, 2.6 mGy; low dose, $<$ 10 mGy; and regular dose, $<$ 20 mGy) were compared with post-treatment cone-beam computed tomography (CBCT). In group 2, consisting of 31 patients with complex midface fractures, pre-treatment shock room CT images were compared with post-treatment CT at different dose levels or CBCT. All images were presented in random order and classified by 2 readers blinded to the clinical results. All cases with an unequal classification were re-evaluated.

Results: In both groups, ultra-low-dose CT had no clinically relevant effect on fracture classification. Fourteen cases in group 2 showed minor differences in the classification code, which were no longer obvious after comparing the images directly to each other.

Conclusion: Ultra-low-dose CT images allowed the correct diagnosis and classification of maxillofacial fractures. These results might lead to a substantial reconsideration of current reference dose levels. (*Imaging Sci Dent 2023; 53: 69-75*)

KEY WORDS: Tomography, X-Ray Computed; Cone-Beam Computed Tomography; Fractures; Bone; Radiation Protection

Introduction

Maxillofacial fractures typically result from sports and traffic and happen to young adults between 20 and 40 years of age, with around one-third in women and two-thirds in men.[1,2] For severely traumatized patients, a standardized shock room emergency protocol including a computed tomo-graphy (CT) assessment of the head, followed by head and neck CT angiography and whole-body CT has been introduced.[3] Maxillofacial fractures can be reconstructed from the head CT. In cases of isolated facial trauma without the need for emergency room management, patients may undergo an isolated maxillofacial CT examination.

The exposure to ionizing radiation associated with CT imaging may increase the potential risk of developing cataracts, as well as salivary, thyroid, and brain cancer.[4] The eye lenses and the thyroid gland are the organs most crucially affected by direct or scattered radiation in the field of maxillofacial imaging.[5] As a consequence, reducing the

radiation dose per scan is a highly desirable goal, as long as the produced images are still diagnostic.

Unlike the standardized shock room protocol, which also aims to visualize potential brain injuries and blunt cervicovascular injuries, isolated CT imaging of the maxillofacial bone has considerable potential for reducing the radiation dose.[4] Considering the high probability that these patients will undergo further radiological examinations for 3D planning and surgical navigation, stereolithographic model fabrication, and postoperative follow-up, the possibility of dose reduction should be strongly acknowledged in clinical routine. In Germany, published diagnostic reference levels (DRLs) include a volumetric computed tomography dose index (CTDIvol) of 20 mGy for CT of facial bones and 8 mGy for CT of the paranasal sinuses.[5] The use of DRLs may guide dose management, but might not represent the full potential of modern dose-saving in CT.[6,7] Previous cadaveric studies of maxillofacial trauma have presented promising results and suggested ultra-low-dose CT imaging at a CTDIvol of less than 3 mGy.[4,8] Therefore, the objective of this study was to evaluate whether such a protocol could be reliably used to classify maxillofacial fractures under true clinical conditions. Since double scanning with ultra-low and standard doses in acute trauma patients was not possible due to ethical concerns, we retrospectively compared fracture classifications from a) isolated trauma cases with pre-treatment CT images at different dose levels (CTDIvol: ultra-low dose, 2.6 mGy; low dose, <10 mGy; and regular dose, <20 mGy) and post-treatment cone-beam computed tomography (CBCT), or b) complex midface trauma cases with pre-treatment shock room CT and post-treatment CT at different dose levels or CBCT.

Materials and Methods

For this retrospective single-center study, pseudo-anonymized data from the clinical routine was used. Ethical clearance was obtained by the ethical committee regulations of our university at the start of this study. The data pool consisted of maxillofacial trauma patients treated at our university hospital between January 1, 2015 and January 8, 2017. The inclusion criteria were a fracture of the midface or the lower jaw and the presence of both a pre-treatment and post-treatment CT examination at different dose levels.

Fracture classification

For an objective classification of maxillofacial fractures, the AO (*Arbeitsgemeinschaft für Osteosynthesefragen*, working group for osteosynthesis issues) Comprehensive

Injury Automatic Classifier (AOCOIAC) of the AO Foundation was used. Fractures were classified based on ascending levels and easily documented with simple software-created code.[7] In this study, the fractures were labeled up to 3 levels (level 1: anatomic fracture site, level 2: description of the disjunction site, level 3: morphology of the fracture). A detailed description of the levels and classification can be found on the foundation's webpage.

IcoView (ITH Icoserve Technology for Healthcare GmbH, Siemens Healthineers, Innsbruck, Austria) was used to analyze radiographic images at the maxillofacial unit of the authors' affiliated university. All images were evaluated on screens with DIN V6868-57 approval for radiographic analysis.

All patient-identifying information was blinded, and the readers were blinded to the clinical reports. The images were presented in random order. Pre-treatment and post-treatment images were classified after a time lag of several days. All images were classified by 2 dental students in their fifth year, well trained in both the anatomy and diagnosis of maxillofacial fractures.

After all images were classified, all cases with an unequal classification between the corresponding pre-treatment and post-treatment images were reviewed in a second round and directly compared to each other under the supervision of a board-certified radiologist who is regularly involved in shock room CT diagnosis and who has more than 15 years of experience. The intention of this approach was to identify the reasons for any discrepancies in the documented AO fracture classification.

The pre-treatment CT scanner and protocols were as follows: CT Discovery CT750HD (GE Healthcare, Vienna, Austria) was used for the initial trauma diagnosis. Severely traumatized patients followed the shock room CT protocol, as described in the Introduction.[3] In this shock room CT protocol, maxillofacial fractures were diagnosed using 1-mm image reconstructions from the CT head at a CTDIvol of 45 mGy (120 kV, 320 mAs). In all other cases, the following isolated maxillofacial scans using 1.0-mm image reconstructions were performed: ultra-low dose: 2.6 mGy (80 kV, 40 mAs), low dose: <10 mGy (100 kV, 50-80 mAs), and regular dose: <20 mGy (120 kV, 60-80 mAs).

The post-treatment CT/CBCT scanners and protocols were as follows: CT Discovery CT750HD (GE Healthcare, Vienna, Austria) was used for isolated maxillofacial scans using 1-mm image reconstructions at an ultra-low dose (2.6 mGy, 80 kV, 40 mAs). CT Somatom Definition AS (Siemens Healthineers, Erlangen, Germany) was used for isolated maxillofacial scans using 1-mm image reconstruc-

tions at a low dose (<10 mGy, 100 kV, 50-80 mAs), or a regular dose (<20 mGy, 120 kV, 60-80 mAs) and 1-mm image reconstructions from head CT at 35-60 mGy (120 kV, 280-350 mAs). CBCT KaVo 3D eXam (KaVo Dental GmbH, Biberbach, Germany) was used for isolated maxillofacial scans at 0.3 mm, 120 kVp, 5 mA, and an exposure time 4 seconds. The CBCT scanner did not provide CTDI vol.

In group 1, the pre-treatment ultra-low-dose CT, low-dose CT, and regular-dose CT were compared with post-treatment CBCT. In 97 patients with an isolated facial trauma (group 1A: fracture of the lower jaw, group 1B: fracture of the midface), pre-treatment CT images at different dose levels were compared with post-treatment CBCT (Table 1).

Table 1. List of groups and number of cases

		Pre-treatment imaging	Post-treatment imaging	Number of cases
Group 1		Ultra-low-dose CT	CBCT	A: 20, B: 20
		Low-dose CT	CBCT	A: 20, B: 17
		Regular-dose CT	CBCT	A: 10, B: 10
Group 2		Shock room CT	Ultra-low-dose CT	5
		Shock room CT	Low-dose CT	1
		Shock room CT	Regular-dose CT	17
		Shock room CT	CBCT	8

CT: computed tomography, CBCT: cone-beam computed tomography

In group 2, the pre-treatment shock room CT was compared with the post-treatment ultra-low-dose CT, low-dose CT, regular-dose CT, and CBCT. In 31 patients with complex midface fractures, the pre-treatment shock room CT images were compared with post-treatment CT at different dose levels or CBCT (Table 1).

Results

In group 1, the fracture codes between pre-treatment and post-treatment images were identical for all 3 dose levels, except for 1 case in which a fracture of the left zygomatic process was no longer visible on the CBCT examination. Although ultra-low-dose CT scans showed greater image noise, non-dislocated fractures and fissures could be sufficiently detected and classified, as validated by the post-treatment CBCT scans (Fig. 1).

In group 2, in the cases with complex trauma requiring a shock room CT protocol evaluation, the classification codes differed in 14 out of 31 cases after the first round (Table 2 and Fig. 2). The differences were observed at all dose levels. After a subsequent review in the second round under the supervision of an experienced radiologist, the differences were no longer obvious after comparing the images directly to each other and could not be related to the radiation dose. In 1 case, an operative reconstruction plate affixed at the non-fractured zygomatic arch led to the impression of a fractured zygoma where no fracture could

Table 2. List of the 14 patients in group 2 with differing AO classification codes after the first round of evaluation (only minor, non-clinically relevant differences)

Post-treatment imaging	CTDIvol (mGy)	AO classification code pre-treatment	AO classification code post-treatment
Ultra-low-dose CT	2.63	Midface92 m.Ol.I0	Midface92 m.Ol.I1
Ultra-low-dose CT	2.62	Midface92 I1.Ol.U1.Oi.I1.Z0	Midface92 I1.U1.Oi.I1.Z0
Ultra-low-dose CT	2.63	Midface92 m.Ol.I1.Z1	Midface92 m.Ol.L1.I1.Z1
Ultra-low-dose CT	2.63	Midface92 I1.L1.U1.Z0	Midface92 I1.L1.U1.I1.Z0
Low-dose CT	7.67	Midface92 I1.m.I1	Midface92 I1.U1.I1
Regular-dose CT	29.31	Midface92 m.Ol.I0.Z0	Midface92 m.Oil.I0.Z0
Regular-dose CT	34.88	Midface92 I1.Olm.U1.L1.I1	Midface92 Z1.I1.L1.Olm.U1.L1.I1
Regular-dose CT	18.79	Midface92 Z1.I1.L1.Oi.U1.Oil.L1.I1.Z1	Midface92 Z1.I1.L1.U1.Oil.L1.I1.Z1
Regular-dose CT	36.31	Midface92 Z0.I0.Oi.m	Midface92 Z0.I0.m
Regular-dose CT	39.01	Midface92 m.Oil.I1.Z1	Midface92 m.Oil.L1.I1.Z1
Regular-dose CT	60.58	Midface92 Z1.Oli.m	Midface92 Z1.Oi.m
Regular-dose CT	56.94	Midface92 Ol.m.Oil.L1.I1.Z1	Midface92 m.Oil.L1.I1
Regular-dose CT	17.91	Midface92 m.Oi.I1	Midface92 m.Oil.I1
CBCT	n.a.	Midface92 U1.Oil.I1.Z1	Midface92 U1.Oil.L1.I1.Z1

AO: Arbeitsgemeinschaft für Osteosynthesefragen (working group for osteosynthesis issues), CTDIvol: volumetric computed tomography dose index, CT: computed tomography, CBCT: cone-beam computed tomography
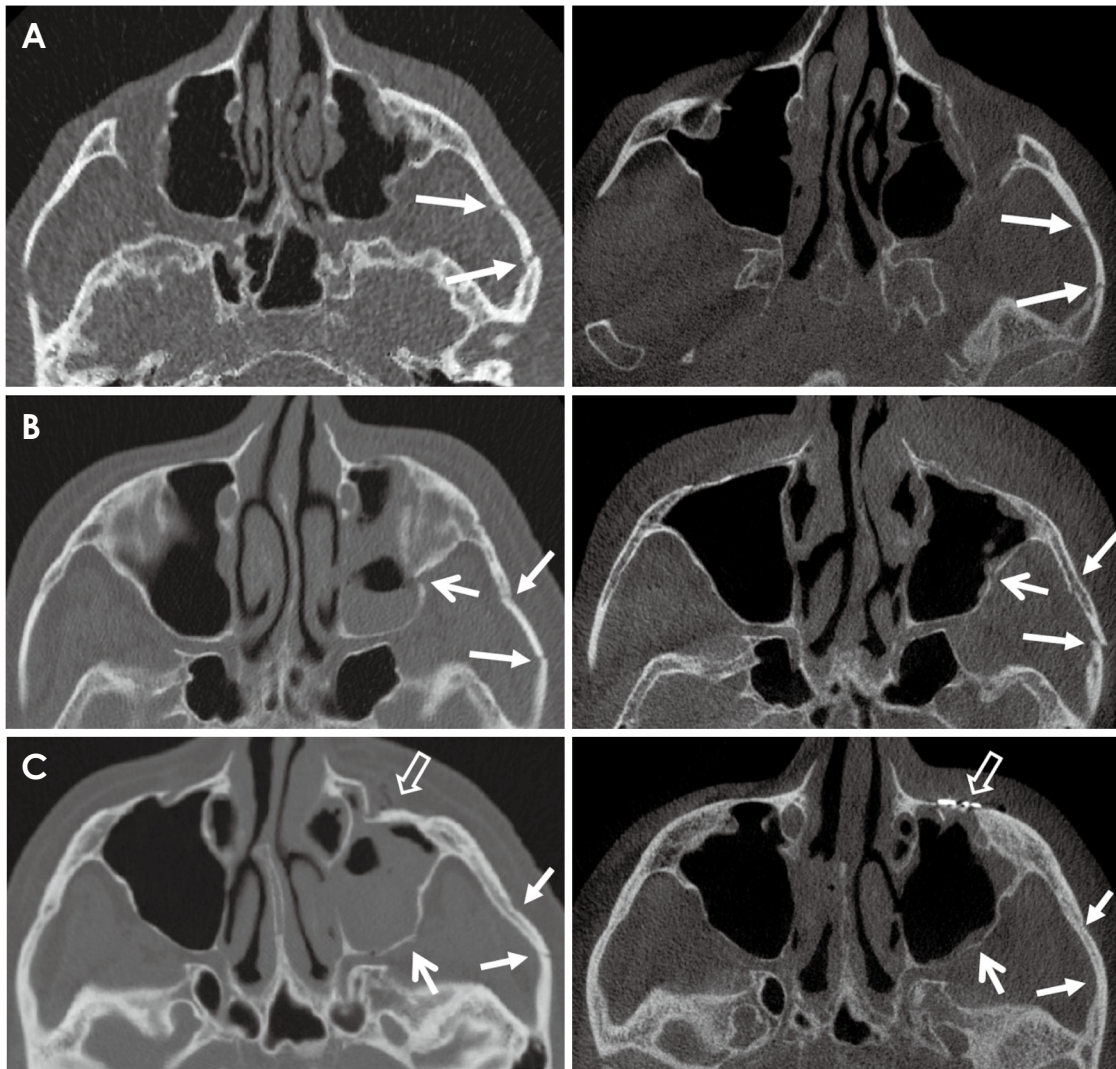
Fig. 1. Group 1. A. Ultra-low-dose computed tomography (CT) (left) vs. cone-beam CT (CBCT) (right). The two fractures of the zygoma (arrows) are clearly identified in both images. B. Low-dose CT (left) vs. CBCT (right). The 2 fractures of the zygoma (fully shaded arrows) and the fracture of the lateral wall of the maxillary sinus (open arrow) are clearly identified in both images. C. Regular-dose CT (left) vs. CBCT (right). After surgery and repositioning of the orbital floor fracture (open arrow), the non-displaced fractures of the left zygoma (fully shaded arrows) are no longer seen. However, the tiny fracture of the lateral wall of the maxillary sinus is still visible (open arrow).

be identified. As the boundary between the lower midface and the intermediate midface was not clearly apparent from the AO classification scheme, fractures in the transition zone were classified differently in 3 cases. In 9 cases, no obvious reasons for the discrepancy in the evaluation were found; nonetheless, all fractures could be seen in both pre- and post-treatment images when compared directly to each other. Therefore, the first reader's inexperience appeared to be causal. In the pre-treatment scan of 1 case, a minimally displaced fracture of the right lateral orbital wall was no longer visible in the post-treatment regular-dose CT scan. As an explanation, the gap in the very thin lateral orbital wall was postoperatively perfectly aligned and invisible and/or already healed.

Discussion

Both surgeons and radiologists are legally responsible for the application of evidence-based CT imaging referral and for applying imaging protocols that guarantee diagnostic radiological examinations with the lowest reasonable radiation dose.[8] The concepts of "as low as reasonably achievable" (ALARA) and "as low as diagnostically achievable" (ALADA) reflect this major aim.[9] Modern CT technology and iterative image reconstruction algorithms could significantly reduce the radiation dose.[10] Widman et al. showed
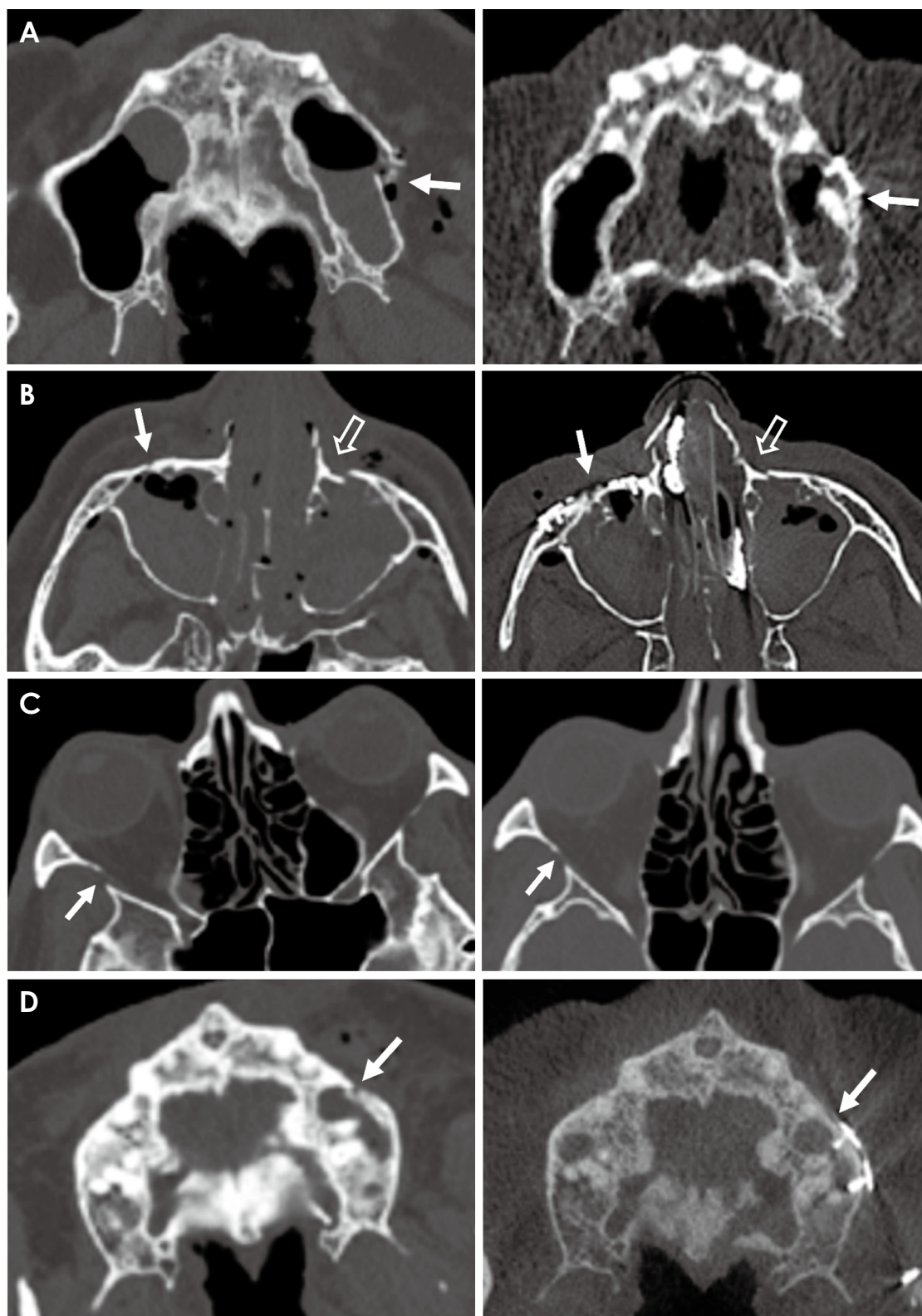
Fig. 2. Group 2. A. Shock room computed tomography (CT) (left) vs. ultra-low-dose CT (right). The fracture of the left maxilla (arrow) has been corrected but is not identified on the post-treatment image. B. Shock room CT (left) vs. low-dose CT (right). The fracture of the right maxilla (arrow) has been corrected, but is not indicated on the post-treatment image. The fracture of the left maxilla (open arrow) is clearly identified in both images. C. Shock room CT (left) vs. regular-dose CT (right). The minimally displaced fracture of the right orbital wall (arrow) is not more detectable on the post-treatment image. D. Shock room CT (left) vs. CBCT (right). The fracture of the left maxilla (arrow) has been corrected but could be identified on the post-treatment image.

that ultra-low-dose CT (CTDIvol < 5 mGy) using adaptive statistical iterative reconstruction and model-based iterative reconstruction enabled more than 90% dose reductions for craniofacial bone and orbital soft tissue imaging.[4,8]

Recent literature has shown the potential of ultra-low-dose imaging for detecting the mandibular canal at a CT-DIvol of 1.74 mGy,[11] linear measurements for oral implant planning at 0.29 mGy,[12,13] CAD-model fabrication at 0.99 mGy,[14] and image-guided surgery at 0.76 mGy.[15] Furthermore, organ-based dose-modulation reduced the dose to the eye lenses by about 27%-50% at an equivalent CTDIvol, without reducing the image quality.[16] The most recent deep-learning-based reconstructions could enable further optimization of ultra-low-dose image quality.[17]

CBCT has often been discussed as a low-dose alternative to CT.[6,7] However, depending on the CT scanner generation and protocol selection, CT could provide dose levels equal to or lower than during CBCT scans.[18] Furthermore, CT offers the advantages of multifunctional, contrast-enhanced trauma imaging from head to toe, with significantly more flexible scan parameters.[19] In periorbital midface fractures, both the bone and the soft tissue are of interest. Post-traumatic fibrofatty tissue entrapment, extraocular muscle herniation, or retrobulbar hematomas cannot be reliably documented with CBCT, and resorbable patch materials during orbital reconstruction are easier to evaluate with CT than with CBCT. A recent study confirmed the superiority of CT over CBCT for soft tissue imaging of the midface.[20] Therefore, CT may remain the preferred image modality in the traumatology setting.

The goal of this study was to prove the feasibility of diagnosing and classifying maxillofacial fractures using ultra-low-dose CT in the real-world clinical routine. The CTDIvol of 2.64 mGy of this protocol was substantially lower than the DRL of 20 mGy for CT of facial bones and 8 mGy for CT of the paranasal sinuses.[5] It was indisputable, that lower radiation dose decreased image quality.[21] However, in isolated mandible and midface trauma cases with a post-treatment CBCT scan (group 1), and in complex trauma cases with a pre-treatment shock room CT scan (group 2), ultra-low-dose CT at 2.6 mGy CTDIvol enabled investigators to correctly diagnose and classify maxillofacial fractures. In 14 out of 31 shock room CT images in group 2 in patients with complex trauma, some minor differences in the AO classification codes were seen. Importantly, these differences were not related to the radiation dose and were no longer obvious after comparing the images directly to each other. Applying the AO classification needed practical knowledge and some training. The advantage of this template and the

classification code is its ability to provide objective and precise documentation of fractures. However, minor differences in subcategories could occur, mainly when describing the extension of fissures in anatomical subregions. These differences were not clinically relevant, as they did not need surgical consideration.

The study has certain limitations. Obviously, a higher number of analyzed cases would have elevated the informative value of the study. Due to ethical concerns, randomized clinical studies using different doses and double scanning in emergency trauma patients will be almost impossible. Nevertheless, this study confirmed a previous cadaveric study and demonstrated that ultra-low-dose CT might be sufficient for diagnosis and classification of maxillofacial fractures in the clinical routine. There are substantial dose differences between the concepts of DRL and ALADA. Future dose management is recommended to focus on ALADA, especially when adopting new scanning devices or reconstruction kernels.

Conflicts of Interest: None

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